Realizing a new e-commerce tool for formation of a virtual enterprise

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Abstract
This paper presents a methodology for the development of a new tool for the formation of a virtual enterprise. The formation phase mainly deals with inviting potential collaborators to virtual enterprise and developing a supply chain; supply chain development is done collaboratively by all the collaborating enterprises. The methodology for realizing a new e-commerce tool is primarily aimed at satisfying the needs of small-to-medium enterprises, and has the following features; Web-based; inexpensive; supports collaboration; and increases pipeline visibility and demand visibility.

1. Introduction

The research problem discussed in this paper is a methodology for the development of a new e-commerce tool for the formation of a virtual enterprise. The two main function of this tool are supporting the selection of collaborators for virtual enterprise and supporting collaborative planning activities for supply chain development. The methodology for realizing a new tool is primarily aimed at satisfying the needs of small- to medium-sized enterprises (SMEs). First, I present definitions of some of the keywords used in this paper:

- *E-commerce*. E-commerce enables the business processes (like buying, making, selling, etc.) among the collaborating enterprise to happen via Internet technology (more preciously, World Wide Web technology). E-commerce enables faster, cheaper, global, and secure means of collaborating for production and sales goods for achieving enhanced customer value.
- *Virtual enterprise*. Virtual enterprise means a nucleus enterprise (or main assembler) joins with a number of collaborating enterprises (supply and distribution enterprises, transporting agents), to manufacture and sell a class of product with the characteristics such as qualitative, agility, and leanness, to achieve maximum customer satisfaction. When market requirements are changed, a new class of products or an improved version of the product should be turned out to meet the new market requirements. In this case, the nucleus enterprise may seek for a new combination of collaborating enterprises that are more suitable to manufacture the new class of products; thus the main aspect of virtual enterprise is dynamic logic of organization and reorganization of collaboration (Davidrajuh and Deng, 2000a).
- *Formation phase*. The life cycle of a virtual enterprise goes through four phases, such as business opportunity identification phase, formation phase, operation phase, and reorganization phase (Enator, 1998; Davidrajuh and Deng, 2000a). The formation phase mainly deals with inviting potential collaborators to virtual enterprise (selection stage of collaborating enterprises) and developing a supply chain for the operation phase. In contrast to traditional supply chain development where the development efforts are solely done by the dominant enterprise, supply chain development for a virtual enterprise is done collaboratively, by the collaborating enterprises.
- *Collaborative planning levels*. There are three levels of planning that can be distinguished depending on the time horizon and importance. These levels are strategic, tactical and operational (Vidal and Goetschalckx, 1977). The strategic planning level is the top level planning (answering questions like what is the market opportunity, how to achieve enhanced customer value, how much money can be made from this business opportunity) that is normally put forward by the nucleus enterprise; changes to the strategic decisions are proposed by the collaborating enterprises. Strategic planning considers time horizons of more than one year. Operational planning level involves short-term decisions (such as how to schedule home delivery vans for today, and how many products are to be picked); time frame for operational planning is often less than a day. Tactical

planning falls in between these two extremes with respect to the time horizon and importance. Tactical planning is the main domain of decision making for collaborating enterprises. Tactical planning is to make as much as money for the individual collaborating enterprise while conforming to the strategic decisions for achieving customer satisfaction. Tactical planning has a more significant effect on the agility of the supply chain, and faces volatile market issues. Once the strategic goals for the virtual enterprise are set, the collaborative planning is done mainly at the tactical level.

- *Supply chain*. A global network of enterprises that collaborate to improve the flows (such as material, information, fund and work) between them. The benefits obtained by the collaboration are improved customer satisfaction, low cost product and/or service, and faster product delivery.
- *Small- to medium-sized enterprises* (*SMEs*). By SME, I refer to an enterprise carrying out small- to medium-scale manufacturing, employing fewer than 100 employees, and an annual turnover of NOK120m. SMEs have been shown to contribute strongly to national economies around the world; generally, SMEs constitute around 95 per cent of enterprises and account for 60-70 per cent of employment in different countries.

1.1 Virtual enterprises of a nucleus enterprise

Figure 1 shows the collaborating enterprises of just two virtual enterprises of a nucleus enterprise. The nucleus enterprise (or the main assembler) is always a member of any virtual enterprise, as it is the formulator, promoter, and principal strategist of these virtual enterprises.

The methodology for development of a new tool is addressed to the nucleus enterprise. The nucleus enterprise is the one which is going to own the Web-based tool (section 4) and pays for the development costs. Thus, the other collaborating enterprises have to pay little overhead costs only; overhead costs like cost of installation on individual computers at the collaborator's site and the maintenance costs. This is beneficial to both the nucleus enterprise and the other collaborating enterprises, because:

- The software is owned by the nucleus enterprise; thus, the software can be used for any other virtual enterprises the nucleus enterprise is currently engaged in or going to establish later.
- Since the costs of participating in a virtual enterprise are low for a potential collaborator, the costs will not hinder or discourage participating.

1.2 Scope of this paper

The methodology for development of a new tool discussed in this paper is applicable for the formation phase of a virtual enterprise; business opportunity identification phase, operation phase and reorganization phase are out of scope of this paper.

1.3 Organization of this paper

A literature review on existing tools for formation of a virtual enterprise is presented in section 2. After going through the literature review, we identify the needs for a new tool. In section 3, we present some basic issues in the formation phase of a virtual enterprise. In section 4, we propose a methodology for building a new, Web-based tool and show how the new tool can be realized. Section 5 presents conclusions.

2. Literature reviewand the problem statement

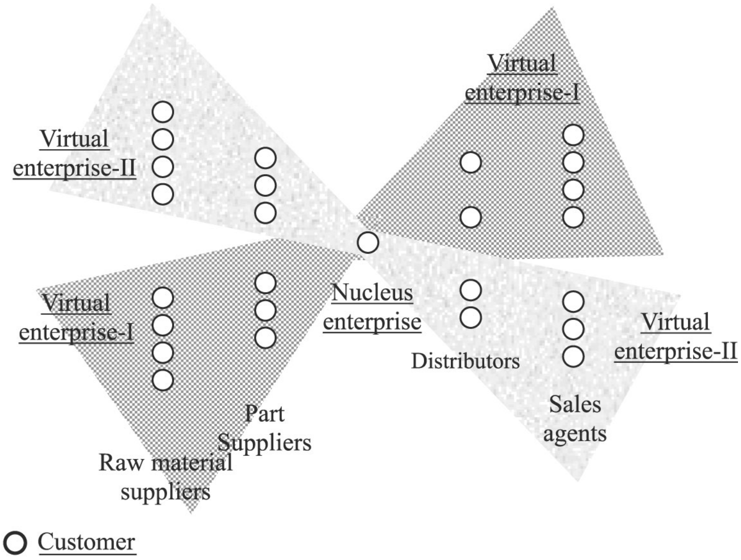
Before forming a virtual enterprise for a project (for production and sale of a class of items), the nucleus enterprise estimates the profitability of the project. This is done in the opportunity identification phase of the virtual enterprise life cycle. Profitability of a product is assessed by extensive market analysis and research. After the opportunity identification phase, the right combination of collaborating enterprises (suppliers, distributors, and transporting agents) must be found to manufacture and sell the product; this is the collaborator selection stage of the formation phase. Then the potential collaborating enterprises agree to the global goals (or constraints) for the virtual enterprise, and individually devise local goals to achieve maximum profits while satisfying the global constraints; this is the supply chain development stage of the formation phase. Thus we identify the two most important tasks in the combined formation phases:

1. inviting and selecting collaborators; and
2. collaboratively developing the supply chain.

A data collection approach for the collaborator selection stage is presented in section 3.1; the literature review given below is on "collaborative supply chain development".

The literature review provides different names for collaborative planning efforts such

Figure 1
Many virtual enterprises of a nucleus enterprise



as "common resource platform" (Fingar and Aronica, 2001), "collaborative, planning, forecasting and replenishment" (Christopher, 2001; Poirier and Bauer, 2000), supply chain "sharing process" (Govil and Proth, 2002), "dynamic trade" (McCullough, 1999), etc. There is a lot of literature proposing a number of concepts, exciting ideas and examples about collaborative planning efforts; but there is a lack of information on adapting these ideas to specific situations. There is little information on how these ideas can be realized into a set of tools that could help managers of SMEs overcome the complexities of dealing with collaborative planning efforts. Even the little information that is available for realizing tools for collaborative planning either use complex techniques such as genetic algorithm (Berry *et al.*, 1998), artificial intelligence (McMullen, 2001), stochastic programming (MirHassani, 2000), statistical analysis (Reutterer and Kotzab, 1999) that require mathematicians or specialists for using it, or demands very expensive and time consuming installation of third party implementation.

Enterprise resource planning (ERP) systems can be regarded as one of the most innovative developments in the information technology of the 1990s (Al-Mashari, 2002). ERP systems have become popular especially among large corporations, as a total enterprise-wide application. ERP systems (such as the ones from SAP, PeopleSoft, BAAN, etc.) are said to cover business processes throughout the entire organization, and integrate different functional areas of the enterprise (Buck-Emden and Galimow, 1996). ERP systems cannot be considered as tools for collaborative planning, mainly because they do not support collaborative planning efforts; they are not designed for integrating with another ERP system from a different enterprise for supply chain planning (though some research reports indicate that different ERP systems can be linked together, e.g. Stine (1999)). In addition, ERP systems are very expensive for SMEs to consider, requiring multi-million dollar budget and large project teams (Willis and Willis-Brown, 2002; Xu *et al.*, 2002); installation and training time for ERP implementation at an enterprise (18-48 months) is also prohibitive for an SME (Govil and Proth, 2002). Besides, ERP systems have other limitations too, such as weak on-demand planning, and do not support quick response to changes in demand (Gormley *et al.*, 1997). Hence, we could conclude that ERP systems are not suitable for formation of a virtual enterprise.

The newer and increasingly popular supply chain planning (SCP) applications can be considered to be close to tools for collaborative planning efforts. SCP applications are from enterprise system solution providers who specialize in supply chain management (SCM) systems (e.g. i2 Technologies, 2002; Manugistics, 2002); the idea behind SCP applications is to allow better B2B relationships and improve production and forecasting simultaneously (Tarn *et al.*, 2002). SCP applications are affordable by SMEs, and have a shorter installation and training time frame than ERP systems. As the name implies, SCP applications are specifically designed for supply chain (whereas, ERP systems are for "all" business processes). However, SCP applications have shortcomings too:

- *Little support for collaboration*. Although SCP applications optimize the internal supply chain of an enterprise, they have little support for inter-enterprise collaborative planning to optimize multi-enterprise supply chain.
- *Limited extensibility*. SCP applications are "application" packages from software vendors; as such, the only way to add more functions to the application when needed, is to buy standardized modules from the vendor.

There is little support available for the enterprise to implement additional functions (other than the ones in the add-on modules) to the applications; outsourcing implementation of custom-specific modules to software vendor could be very costly.

2.1 Statement of the problem

There is a lack of e-commerce tools to support the formation of virtual enterprise. Managers of SMEs are looking for a tool that could help them design the strategic model of the supply chain in which they are collaboratively involved. The tool should let them understand how their strategic decisions, and the ones of their partners, contribute to tactical decisions and thus the success of the whole supply chain. The ideal tool for formation of virtual enterprise should:

- Invite potential collaborators to virtual enterprise.
- Support collaborative "inter-enterprise" planning efforts.
- Allow easy realization and be extensible: the concept, methodology and techniques behind the tool development should not be complex. Extensions to the tool should be done easily, and preferably in-house.
- Not be very expensive: cost of the tool should not prohibit enterprises from participating in virtual enterprise. Since there is inconclusive support for the hypothesis that investment in IT pays off (Brynjolfsson and Hitt, 2000) and due to the newness of e-commerce technologies, managers of SMEs are certainly reluctant to make huge investment in e-commerce tools.
- Improved pipeline visibility and demand visibility: with the tool, the managers should be able to easily evaluate the effect of their simulation trials on the supply chain to meet demands.
- Be user-friendly and allow quick installation and training.

3. Formation of a virtual enterprise

In this section we shall go through some issues about the formation phase of a virtual enterprise. The main stages of the formation phase are the selection stage and supply chain development stage. The issues that are discussed here are relevant to the proposed methodology for building a new tool. The methodology is presented in section 4.

3.1 Some issues in the selection stage

The nucleus enterprise is the one that initiates collaboration. For example, let us say that a computer manufacturer is planning to build a new personal desktop computer line; let us call the model MP X-Tec (Model Pentium eXtended Technology). First the nucleus enterprise will set the overall guidelines for the collaboration (so-called strategic decisions or global constraints). An oversimplified global constraint is given below:

```
<?xml version="1.0"?>
<!DOCTYPE ProductData SYSTEM\par
"http://www.computerHWmanu.Co.uk/
ProdDataSpec.dtd">

<ProductData>
  <key>productNo</key>
  <value>030973</value>
  <key>productName</key>
  <value>MP X-Tec</value>
  <key>pricePerUnit</key>
  <value>USD 2000</value>
  <key>amount</key>
  <value>2000</value>
  <key>delivery</key>
  <value>10</value>
  ... ... ... ...
</ProductData>
```

The piece of structured information given above indicates that the computer manufacturer has decided to make a new model called "MP X-Tec", which shall cost US$2000 to the end consumer. It also reveals that the model will be made in 2,000 units per batch (for example, to distributors) and it should be delivered to the consumer within ten days after booking. In addition, the enterprise will open a table with some entries about the raw materials needed and the projected outputs (see Figure 2).

After setting the global constraints, the nucleus enterprise will proactively invite all partners known to it (such as the raw material suppliers (suppliers' supplier), part suppliers, distributors, and sales agents) for collaboration.

Referring to Figure 2, let us say that a supplier is interested in supplying sound

Figure 2
Initial table with the host

					Raw materials for NE	Products from NE					
					<key>productName</key> <value>**Harddisk**</value> <key>pricePerUnit</key> <value>**USD 168**</value>	<key>productName</key> <value>**MP X-Tec**</value> <key>pricePerUnit</key> <value>**USD 1600**</value>					
					<key>productName</key> <value>**Sound System** </value> <key>pricePerUnit</key> <value>**USD 200**</value>						
					… … … …	**… … … …**					
					… … … …	**… … … …**					

system (sound card, speakers, amp, cables, etc.) to the computer company. Out of the product definitions shown in Figure 2, the supplier will estimate how much money it can make, how long it will take, and how much raw materials will be needed and costs, etc. If satisfied with the estimations, the supplier will fill up the table (see Figure 3), inviting a sub-supplier for collaboration.

Figure 4 shows that a distributor in New Jersey is now interested in joining the virtual enterprise. It is interested in buying MP X-Tec from the computer manufacturer at the listed price US$1,600 apiece, and now looking for sales agents in New Jersey who are willing to buy for US$1,800 apiece from it. It must be remembered that sales agents must sell the computers for less than US$2,000 to end consumers (global constraint).

From Figures 2-4, it is clear that the collaboration table is started with the nucleus enterprise (in the middle of the table) and then gradually grows in both directions as more and more suppliers and distributors are added. Although Figures 2-4 look like two-dimensional tables (linear chain), it is actually a multi-dimensional one (a web of enterprises).

It must be noted that in a "pure-play" type business-to-consumer e-commerce (B2C EC), the computer manufacturer sells computers directly to the customer with the help of Web sites; a "click-and-mortar" type B2C EC enterprise either can sell the products directly to customers over the Internet or through the traditional distribution channels.

3.2 Some issues in the supply chain development stage

Figure 5 shows just five enterprises as potential collaborators. Figure 5 also shows the two planning levels, strategic planning level and the tactical planning level. Potential collaborators will make tactical decisions (constrained by the strategic decisions) to make money. To help make tactical decisions, each enterprise's supply chain activities are grouped into the three fundamental groups of activities such as purchasing activities, making activities, and selling activities. Govil and Proth (2002) identify five fundamental activities such as buy, make, move, store, and sell; for simplicity, we group make and store together as making, and move and sell and selling.

Potential collaborators evaluate whether the collaboration is profitable to them by running simulation trials on the fundamental activities. If a potential

Figure 3
A supplier is added as a potential collaborator

				Raw materials for Supplier	Raw materials for NE	Products from NE					
				<key>productName</key> <value>**Speaker 25W**</value> <key>pricePerUnit</key> <value>**USD 05**</value>	<key>productName</key> <value>Sound System</value> <key>pricePerUnit</key> <value>USD 200</value>	<key>productName</key> <value>MP X-Tec</value> <key>pricePerUnit</key> <value>USD 1600</value>					
				<key>productName</key> <value>**Cable coaux**</value> <key>pricePerMeter</key> <value>**USD 0.80**</value>	… … … …	… … … …					
				… … … …	… … … …	… … … …					
				… … … …	… … … …	… … … …					

Figure 4
Some more enterprises as potential collaborators

	Raw materials for Supplier	Raw materials for NE	Products from NE	Products from Distributor	
	<key>productName </key> <value>Speaker cloth</value> <key>pricePerUnit </key> <value>USD 05 </value>	<key>productName </key> <value>Sound Sys </value> <key>pricePerUnit </key> <value>USD 200 </value>	<key>productName </key> <value>MP X-Tec </value> <key>pricePerUnit </key> <value>USD 1600</value>	<key>productName </key> <value>**MP X-Tec** </value> <key>pricePerUnit </key> <value>USD **1800**</value> <key>salesArea </key> <value>**NJ**</value>	
	<key>productName </key> <value>Cable coaux </value> <key>pricePerMeter </key> <value>USD 0.80 </value>	… … … …	… … … …	… … … …	
	… … … …	… … … …	… … … …	… … … …	
	… … … …	… … … …	… … … …	… … … …	

collaborator could not make a workable tactical decision that will bring money, certainly the enterprise will propose changes to the strategic decisions ("agile", adjusting to the new situation); otherwise, that enterprise will not become a member of virtual enterprise.

3.2.1 Supply chain activities

Potential collaborators (in Figure 5) purchase raw material (by purchasing activities), turn it into products or semi-products (making activities), and then sell (selling activities). Each of these activities changes the state of the material that flows through the supply chain (see Figure 6). When we say "the state" of the material, we limit our scope to:

- the accumulated cost of material;
- the time taken for the material to reach its current point from the time it has entered the virtual enterprise; and
- the total amount of it (number of units).

In Figure 6, an activity is represented by a rectangle; circles represent the input and the output (buffers). When an activity is carried out, the input material is removed from the input buffer and the products (or semi-products) placed into the output buffer. In addition, the state of the material that is subjected to the activity is changed. As shown in Figure 6, the changes to the state of the material owing to the activity are limited to simple arithmetic calculations.

Figure 5
Collaborative supply chain planning

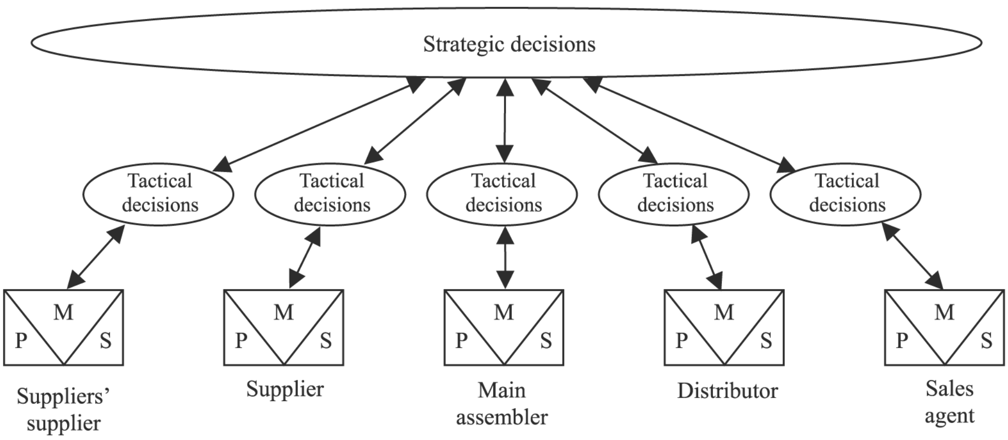
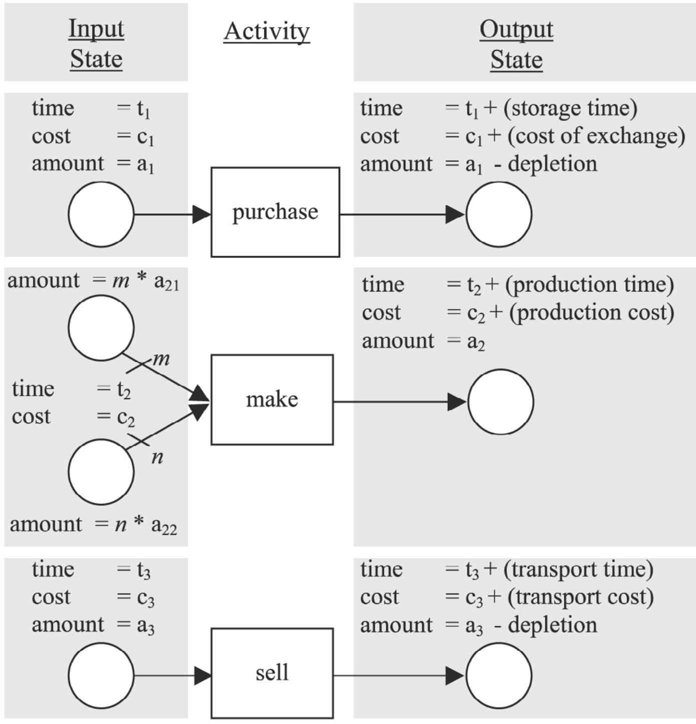


Figure 6
Supply chain activities



3.3 Iterative process of tactical decision making

A potential collaborator starts with its fundamental activities and verifies whether the change of state (in cost, time, amount) of the product leaving the enterprise conforms to the tactical decisions set by the enterprise for itself. If not, the enterprise must alter the parameters of its activities (e.g. reducing production time by hiring extra humans and machinery). When all the potential collaborators individually satisfy their tactical decisions, then they can verify whether the combined activities of the virtual enterprise satisfy the global constraints (on the cost of the final product leaving the virtual enterprise, the quality, delivery time, in right amount, etc.). In case the combined activities do not satisfy the global constraints even if the local constraints are met individually, then a new set of tactical decisions should be made and the collaborating enterprises should start planning their manufacturing activities adhering to the new set of constraints. Clearly, according to the way we present here, the planning efforts for formation of a virtual enterprise are an iterative process.

3.4 Modeling a virtual enterprise

In Figure 6, the supply chain micro activities (or fundamental activities) are represented as Petri nets. Petri net is a simple yet powerful discrete mathematical tool for modeling and simulation of discrete events systems. In Petri nets, the activity is represented by a rectangle and called “event” and the buffer (input, output) is represented by a circle and called “place”.

In Figure 6, Petri net models enable the collaborators to estimate the costs, material flow amounts, and times of the micro activities. It is also then possible for a potential collaborator to find its overall cost, profit, timing, etc. for participating in the virtual enterprise, by combining the activities. However, it will not be possible to provide an overall estimate for the whole virtual enterprise simply by combining the overall estimates for the individual collaborators. This is because the virtual enterprise may consist of hundreds of potential collaborators and, most importantly, these potential collaborators are dynamically attached the virtual enterprise during the formation phase; when a potential collaborator is persuaded to join, it enters the supply chain development process by running trial simulations on its activities; then, if not satisfied, it leaves. Therefore, for simulation of a virtual enterprise with hundreds of dynamically attached potential collaborators, a different approach for combining the models of individual collaborators is needed.

Davidrajuh (2000) shows a Petri net approach for simulation of a virtual enterprise by combining the collaborators at a higher level above the Petri net level (lower-level). At the higher level, the potential collaborators are connected together using the software called AgileSIM (Davidrajuh, 2000). When the higher-level model of a connected system is complete, the AgileSIM software automatically generates the lower-level Petri net model that can be used for simulation. In the higher-level model, the potential collaborators are connected together dynamically; this means a collaborator may be deleted from the connected model by an operation that takes constant time O(1), meaning – the deletion operation is independent of the number of collaborating enterprises currently attached to the virtual enterprise. Similarly, adding a new collaborator to the collaboration also takes constant time.

Figure 7 shows a lower-level Petri net model of a virtual enterprise converted from a higher-level model by AgileSIM. In the Petri net model, a single Petri net event-place pair represents each collaborator. In addition to the material suppliers, part suppliers, e-tailer, and customer, the transporting agents are also included in the Petri net model. There is a limitation in the approach by Davidrajuh (2000, 2002): basic simulation engine for material flow through supply chain is based on a "pull" principle. In pull material flow, demand triggers the flow; by "push" principle, material is moved with anticipated demand. As most of the enterprises practice hybrid "push-pull" flows, the simulation engine should be upgraded to a hybrid type. In Figure 7, the nucleus enterprise of the virtual enterprise is referred to as an "e-tailer"; this is because a pure pull-based material flow system is not suitable for any business-to-business e-commerce system, but applicable to a business-to-consumer (B2C EC) pure-play type enterprise (an e-tailer).

We propose the following improvement to the basic engine for simulation: in addition to the pull engine, the AgileSIM should also generate a parallel push engine. This change could be easily made as close observance reveals that the difference between a pull engine and a push engine is basically reversing the direction of flow. While the pull engine enables order flow, and the material flow triggered by a customer order, the push engine may take care of the operations such as move (for moving material between enterprise in advance as inventory), and store for storing materials in warehouses. A combined pull and push engine could be used for simulation of a virtual enterprise as a part of any B2B EC enterprise in addition to B2C EC enterprise.

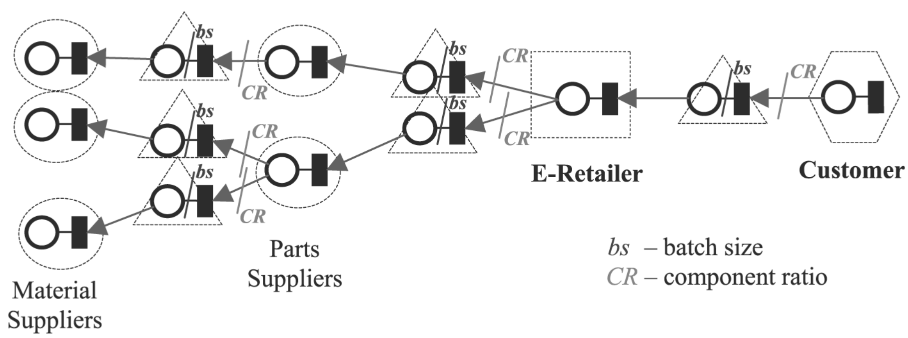
4. Towards development of a new tool

In the subsection 2.1, we presented some of the characteristics of an ideal tool for formation of a virtual enterprise. In section 3, we studied some of the issues that are relevant to the formation phase. In this section, we shall elaborate the characteristics of an ideal tool leading to a methodology for building a new tool. Lets go through the characteristics of an ideal tool, one-by-one.

4.1 Inviting potential collaborators to virtual enterprise

After the nucleus enterprise has outlined the global decisions for a new project, it should employ an e-commerce tool to proactively invite potential collaborators. Davidrajuh and Deng (2000a, b) present a data collection

Figure 7
Petri net model of a virtual enterprise under development



Source: Davidrajuh (2002)

system where mobile agents are used to search for potential collaborators. In addition, the nucleus enterprise may also invite its collaborator from previous collaborations (virtual enterprises). There are some limitations on using the data collection systems proposed in Davidrajuh and Deng (2000a, b): the product data on potential collaborators' Web sites must be structured data (XML) conforming to a common document type definition (DTD).

4.2 Support collaborative "inter-enterprise" planning efforts

To support planning efforts of geographically distributed collaborators, we must make use of Web technology. The tool must be Web-based, offering Web interface to function for running simulation trials on the fundamental activities. The tool should also offer interface to a database with a common area with access privileges for all collaborating enterprises and restricted areas to individual enterprises for their temporary data storage and retrieval. Figure 8 shows that the potential collaborators could use the tool to devise their tactical plans by running simulation trials on the activities. In addition, simulation of the whole virtual enterprise consisting of many potential collaborators is also possible (section 3.4).

4.3 Improved pipeline visibility and demand visibility

A simple way of improving pipeline visibility and demand visibility is to offer a public place where the data that are of interest to all the collaborating enterprises can be stored. Figure 9 shows the tool providing interface to the database. Individual enterprises have exclusive access to their respective areas. This area can be used to store temporary values for simulation of their activities. There are also public areas where, in addition to other information for common consumption, the consumer demands are placed. When an individual enterprise tries to simulate its activities that are of an inter-enterprise nature (say purchasing raw material from a raw material supplier), it retrieves data from public areas of other enterprises. However, an enterprise may confine it to its private area for operations like make.

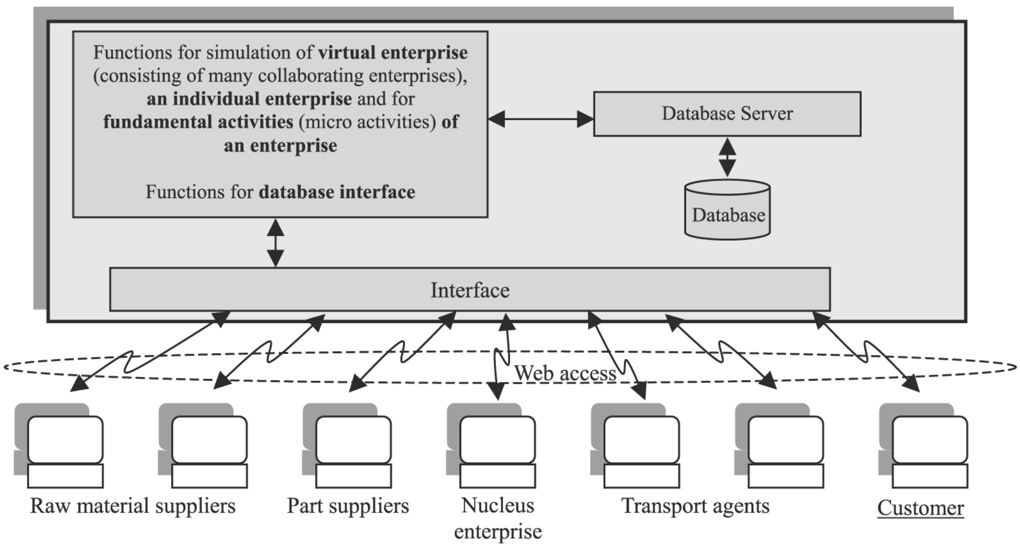
4.4 Easy realization and extensible tool

Rather than coding the function for simulation in a general purpose programming languages (like C++, Java), it is highly advisable to program using MATLAB (Mathworks, 2002) language. With MATLAB, it is very easy to program complex functions for Petri net manipulation, as MATLAB offers hundreds of in-built mathematical functions. In addition, using BASIC, like MATLAB programming language, is also easy to program. In addition, it is easy to add more functionality to program modules written in MATLAB (easily extensible).

4.5 Inexpensive tool, allowing quick installation and training

Figure 10 shows deployment of the proposed tool as embedded software within the

Figure 8
Architecture of a Web-based tool for formation of virtual enterprise



MATLAB Web Server. Since the tool is installed on the nucleus enterprise's Web server, the collaborating enterprises only need a Web browser (such as Netscape Navigator or Microsoft Internet Explorer) to interact with the tool. Since a Web browser could be obtained free of charge these days, collaborating enterprises have to share only the maintenance costs of the tool. By using the Web browser, collaborators need not install the tool on their local computers.

With the help of MATLAB Web Server, training time is also minimized: the users of the tool need not learn the internals of the tool or about MATLAB. They only need to learn how to use the menu-driven Web pages of the tool.

4.6 A timetable for the development of a new tool

A probable timetable for the development of the new tool is shown in Table I. According to Table I, the development is planned in five stages. Stage I is about developing the functions for simulation of micro activities. On the successful completion of stage I, in stage II, the parallel push and pull simulation engines can be implemented. In stage III, the Web interfaces should be constructed. Thus, by completion of stage III, test versions of the tool could be tested from remote computers.

Stochastic components

The Petri net models shown in Figures 6 and 7 are deterministic models. In stage IV, stochastic components could be added to the functions to take care of non-deterministic mechanisms that are elements of any real-life supply chains.

Sharing and security

Stage V is the last stage of development in which sharing and security are the main issues. The debates like "how we can make

Figure 9
Providing demand and pipeline visibility through a common database

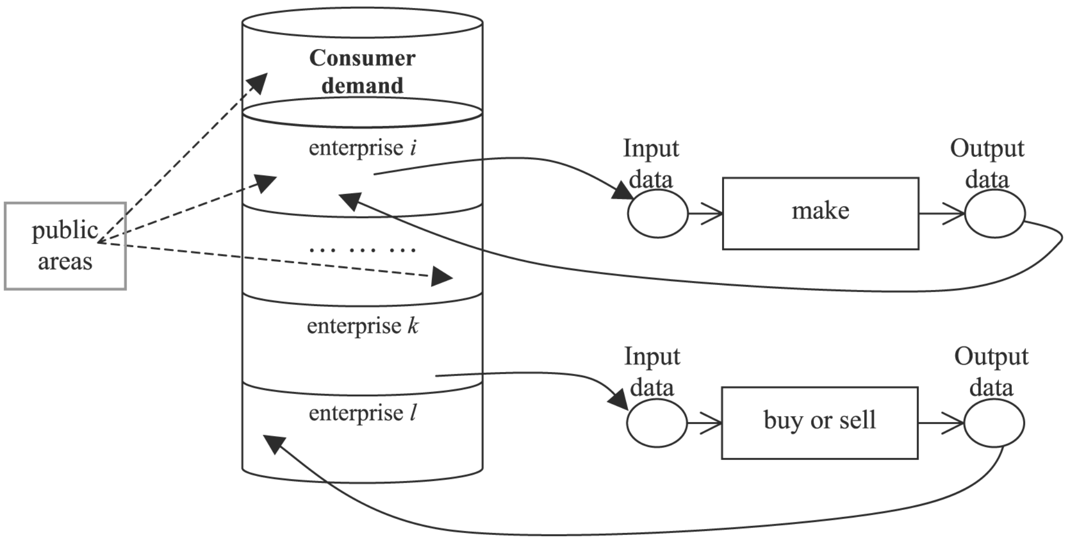


Figure 10
MATLAB Web server based architecture

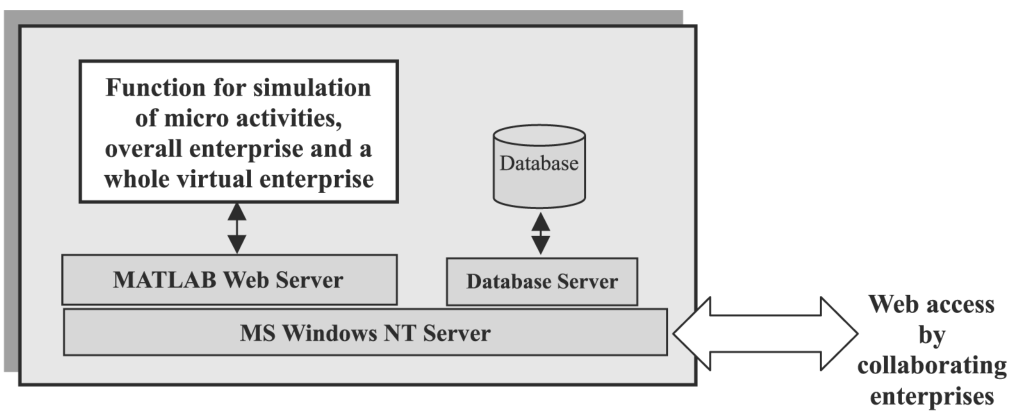


Table I
Development of a new tool for formation of a virtual enterprise

Stage	Main aspect
I	Functions for simulation of micro activities
II	Simulation of a virtual supply chain
III	Collaboration using Web technology
IV	Adding non-deterministic components
V	Sharing and security

sure that that sharing of information, benefits, and losses between collaborating enterprises", are encountered here. The second issue is security: security and privacy are important in any peer-2-peer system; therefore, security measures should be added to the tool to protect individual collaborating enterprises from hacking, hampering, snooping, etc.

5. Conclusion

This paper discusses a methodology for developing a new tool for formation of virtual enterprise. We started with a literature review of existing tools for this purpose. Then we identified the needs for a new tool that is low-cost, Web-based, faster installation and training, and easily extensible. Then we proposed a methodology for development of a new tool that is based on both pull-and-push type material flow control, and uses deterministic Petri Net model. The benefits reaped with the help of this tool are: agile (fast adaptation) virtual (allows dynamic participation of enterprises) enterprise that is customer-focused (global constraints are for enhanced customer value), provides visibility (direct access to information for all the collaborating enterprises), and direct access to a web of common computing tools (to eliminate incompatibility problems).

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